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NEW CONTRIBUTION IN THE THEORY OF TURBULENT FLOWS

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ABSTRACT. A new contribution to turbulent flow theory, included in the book of M. D. Millionshchikov, is discussed. The approach includes the utilization of the principle of superposition of molecular and turbulent viscosity effects and involves a simplified method for the calculation of pulsation velocity.

Cover Page Source

The turbulent (vortex) flow of a gas or of a fluid is one of the most complex and remarkable physical phenomena. Look at the stormy flow of water in a mountain stream, at the jet which comes from a fire hose, or at flakes borne by the wind. The irregular nature of the flow is noted at the first glance. The turbulent motion is stationary only on the average. The rate of flow at each point as well as the displacement velocity of each particle of matter changes both in magnitude and in direction in a random manner. But the merging of random pulsations gives average values of physical quantities which are reproduced very well in the repetition of experiments and depend uniquely on test conditions. /74*

In the kinetic theory of gases fundamental significance is attributed to the processes of the molecular transfer of matter, energy and momentum, which are described by means of coefficients of diffusion, thermal conductivity and viscosity. The close analogy between these three processes and their physical mechanism becomes clearer if we redefine somewhat the coefficients of thermal conductivity and viscosity, replacing these with thermal diffusivity and kinematic viscosity, respectively (the word "coefficient" is omitted for brevity). After this all three coefficients have the identical dimension cm^2/sec. In agreement with kinetic theory all of these (with a numerical factor accuracy close to unity) are obtained by multiplying the mean square velocity of the random thermal motion of molecules by the length of their free path.

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* Numbers in the margin indicate pagination in the foreign text.

Long ago it was proposed to describe turbulent transfer, in an analogy with molecular transfer, by means of a turbulent transfer coefficient, which was also obtained by multiplying velocity by length. In view of the so-called turbulent motion pulsation velocity plays the role of random velocity and the displacement path 1, which was introduced for the first time in the classical works of Prandtl, serves as an analogue of the free path length. However, the formulation of an exact quantitative theory of turbulent flows is connected with a great deal of difficulty.

In approximation theories the flow region is arbitrarily divided into zones, in one of which molecular transfer is disregarded, and in the other, turbulent transfer is disregarded. /75

If the flow interacts with the solid surface then the transfer processes occur basically in the boundary layer near the surface. The flow, in turn, separates into two parts. A thin film adheres directly to the surface where motion occurs as in ordered (laminar) flow, and the impulse transfer is accomplished through molecular viscosity. This film is called the laminar or viscous sub-layer. It has been considered that in the remainder of the flow it is not necessary to consider molecular transfer.

Recently some new interesting results were obtained in this area[1]. In order to obtain these results the principle of superposition (overlapping) of the effects of molecular and turbulent viscosity were employed. Everywhere, except in the laminar sub-layer the contributions of turbular and molecular mechanisms are combined in the pulse transfer. Here the calculation method is not complicated in the mathematical sense due to a simpler determination of pulsation velocity. If in the Prandtl method the pulsation velocity value was determined by the average velocity flow gradient, then in the new method we employ the so-called dynamic velocity which is expressed very simply by the flow resistance.

How well the proposed method describes the average velocity distribution in a turbulent boundary layer is apparent from the drawing where the continuous curve is plotted according to the formula of M. D. Millinoshchikov, and points represent the numerous result of careful measurements of a number of large-scale experiments. The average flow velocity is represented along the vertical axis in dynamic velocity units, and the horizontal axis shows the logarithms of distance from the surface, expressed in the form of the well-known dimensionless variable η. Previously existing theory permitted the determination of velocity distribution only in a well-known turbulent region, i.e., with values η greater than 200($\log \eta > 2.3$). It is apparent from the drawing that the new method gives excellent agreement with experiment over the entire range in which measurement results are available.

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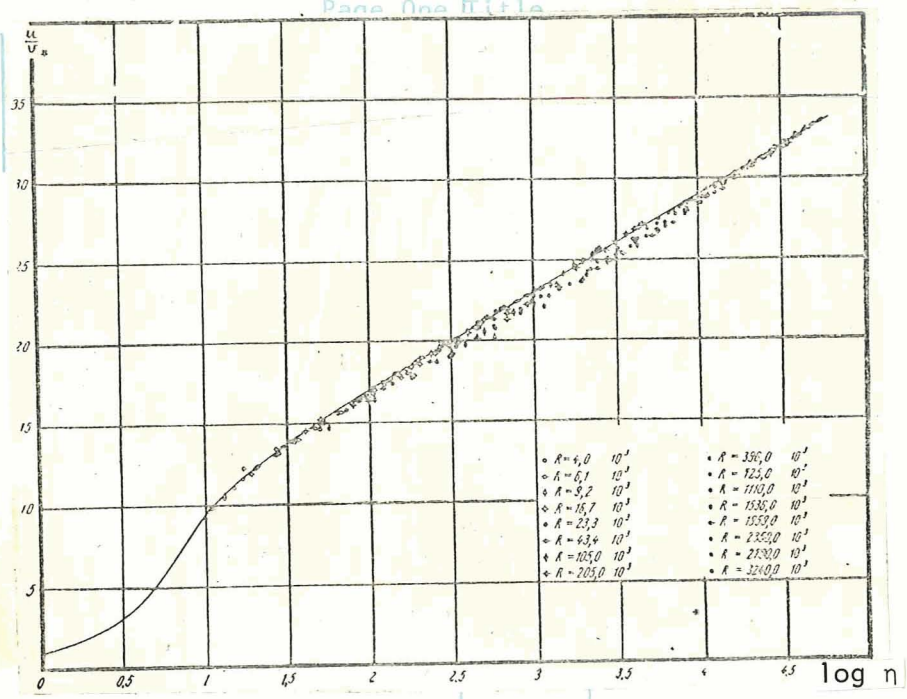
1 M. D. Millionshchikov, Turbulentnyye Techeniya v Pogranichnom Sloye i v Trubakh. Turbulent Flows in a Boundary Layer and in Pipes, Nauka Press, Moscow, 1969.



Average velocity distribution in a turbulent boundary layer. The continuous curve is computed according to the formula of M. D. Millionshchikov, and the points represent experimental results. Average flow velocity is represented along the vertical axis and the logarithm of a dimensionless value which expresses distance from the surface is represented along the horizontal axis. Velocity units represent dynamic velocity.

When the velocity distribution is known it is possible to calculate the coefficient of resistance. The agreement of theory with measurement could not be better. For flow near a smooth surface the displacement path is considered to be proportional to the distance of the point examined from the surface. Where roughness is concerned M. D. Millionshchikov combines the three contributions to the pulse transfer: molecular viscosity and two forms of turbulent viscosity, in one of which the displacement path remains as before, and in the other in which $\bar{k}$ is assumed to equal the average height of projections. Here agreement between experiment and theory is very good.

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